cyclonic circulations. These *temperature* gradients may profitably be compared with the gradients in high or low *pressure* areas taken as a whole. The departure of the temperature in each sector from the prevailing mean air temperature is evidently the basis for a thermodynamic discussion of the cyclonic problem.

RESULTS.

We conclude that there is no fundamental difference in the structure of American and European cyclones and anticyclones. The observed temperature distribution is in harmony with the observed atmospheric currents, and is due to an intermixture of currents from warm and cold latitudes, the energy of storms being thus referred to the heat transported from different latitudes. The pressure centers of motion occur on the boundaries of these countercurrents, and thus represent the dynamic effects of the thermodynamic energy. Instead of vertical convection being the primary cause of storms it is rather horizontal convection, interchange of heat energy on the same levels, as suggested in my preceding papers. There is no evidence of the superposition of cold-center cyclones upon warm-center cyclones, as expounded by Clayton or by Bjerknes and Arrhenius, nor are there purely dynamic vortices in a rapid stream as supposed by Hann, nor are there cyclonic vortices caused by atmospheric islands of high pressure obstructing a rapidly flowing eastward drift as explained by Shaw, or by Hildebrandsson in his report to the International Committee, 1905.

ATMOSPHERIC ELECTRICITY.

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The study of meteorology may be pursued with two entirely different ends in view. We may pursue it for utilitarian purposes, or we may pursue it as a pure science for the knowledge to be derived from it. It must be admitted that there are a number of so-called meteorologists whose point of view is the former, and whose highest ambition is the production of an almanac giving the state of the weather for each day a year in advance. Although some of the great advances of knowledge which have been of practical use to mankind have been made by the utilitarian student, yet experience has shown that without the pure scientist little real advance can be made. The true men of research, working for the sake of science itself, have always been the pioneers to open up new country and reveal new treasures, which the utilitarian has then appropriated and used. In meteorology we must not expect and seek for merely practical knowledge, but must investigate the atmosphere in a truly scientific manner, considering no phenomenon found in it to be unworthy of investigation. Thus although the electrical conditions of the atmosphere on a fine day are insignificant in comparison with the great motions of the atmosphere, or with the local conditions which determine the climate and weather of any place, yet meteorology can not be complete without a true knowledge of these conditions. While meteorologists must always be more concerned with the great changes in the motion, temperature, pressure, and humidity of the air, they must also not forget that electricity plays an important part in natural phenomena. Since the time of Franklin great progress has been made in our knowledge of the electrical conditions of the atmosphere, but so far the progress has led to no utilitarian results, and the problems of the thunderstorm are not yet solved. In the present article an attempt is made to sketch, in as few words and as simply as possible, the lines along which research has traveled.

One of the first lessons we learn on being introduced to the science of electricity is that a positively charged body placed between two others, one having a positive and the other a negative charge, will tend to move toward the latter. This we are told is due to the "electrical field" set up by the oppositely charged bodies.

The experiments of Franklin showed that such an electrical field exists in the atmosphere during thunderstorms. Later observers have shown that not only during thunderstorms, but also under normal circumstances, there is an electrical field in the lower atmosphere, such that a positively charged body would be attracted toward the surface of the earth. The electrical field of the lower atmosphere points to the permanent presence of a layer of negative electricity on the surface of the earth with a corresponding positive charge somewhere above the surface, but exactly where this positive charge is has been the subject of much controversy.

For a long time it was thought that the negative charge on the earth is a charge left there when the earth first became a separate member of the solar system. If that had been so then the corresponding charge of positive electricity would be somewhere right outside the earth and its surrounding atmosphere, in fact somewhere in cosmical space. We should thus have expected an electrical field, similar to that found near the surface of the earth, extending with only slightly diminished intensity to heights much greater than those of our atmosphere; but observations made in balloons have proved most conclusively that the electrical field found near the surface has nearly disappeared at a height of four and one-half miles (reached by Gerdien, November 5, 1903). This means that the outside positive charge corresponding to the negative charge on the surface of the earth is not outside the atmosphere, but is *distributed through the whole mass of air in the lower atmosphere.*

This result leads us to consider under what conditions electricity can exist in the atmosphere. Until 1900 the conception was firmly held by physicists that the air of the atmosphere in its normal state is a perfect nonconductor of electricity, and that if a charged body, perfectly insulated, were placed in air quite free from dust the charge would be retained indefinitely. That such a body never does permanently keep its charge was always ascribed to the presence of dust in the air. It was supposed that particles of dust coming into contact with the body take a part of the charge and are then repelled, and that thus in course of time the charge is in this way entirely dissipated on to the dust of the air. But in 1900 Elster and Geitel in Germany and C. T. R. Wilson in England showed that not only does a perfectly insulated body in perfectly pure air lose its charge, but that the presence of dust diminishes the rate of loss instead of increasing it.

Just before this time new ideas had been formed as to what takes place during the discharge of electricity through gases. It had been demonstrated that most, if not all, the phenomena then known to accompany the discharge of electricity through gases could be explained by assuming that an electrically neutral molecule of a gas can be split up into two other molecules or two atoms, each of which carries an electrical charge, one negative and the other positive. To these charged molecules the name "ion" had been given, an "ion" being understood to be any small material particle, generally of molecular dimensions, which carries a charge of electricity.

Elster, Geitel, and Wilson at once pressed this theory into service to explain the results of their experiments. They assumed that a small proportion of the molecules of ordinary air are always being split up into ions. Thus when a charged body is introduced into air the electricity on it attracts ions of the opposite sign which neutralize the charge, or in other words the charge is dissipated. Numerous experiments were made to prove or disprove this theory, but it has withstood all the tests and is now generally accepted. Elster and Geitel proceeded to work out in full the bearings of this new theory on the problems of atmospheric electricity. It at once became obvious that if there are always both kinds of ions in the atmosphere the negative charge on the earth will attract the positive ions toward itself, become neutralized and so disappear. That such a process is always taking place has been clearly shown, and Elster and Geitel designed an instrument for measuring the rate at which the charge on the earth is being dissipated. The recognition of this process led to an important advance in the study of atmospheric electricity; it indicated that there must be some influence at work in the lower atmosphere the presence of which had never been suspected before.

The new position of affairs may be summed up as follows. We find a layer of negative electricity spread over the entire surface of the globe with a corresponding charge of positive electricity distributed through the mass of the lower atmosphere. At the same time we find the molecules of the air splitting up into positive and negative ions, the former of which must be attracted to the negative charge on the surface of the earth, while the latter attach themselves to the positive charge in the air; so that if these were all the processes then the charge on the surface and the charge in the air would both be neutralized within a very short time. The fact that they are not neutralized points to some influence constantly at work in the lower atmosphere, which renews the charge on the earth and that in the air as fast as they are neutralized.

This influence is at present entirely unknown, but perhaps no single physical problem has been more assiduously attacked and more freely discussed. The search for the solution has been keen and energetic; it has led to great experimental and observational activity; it has led also to the publication of innumerable theories, most of which have rapidly succumbed to hostile attacks. We can not here go at length into the controversy which has developed around this problem, but we must indicate the lines along which a satisfactory theory must be drawn. We have constantly in the air free positive and negative electricity in the form of ions; all that is required to solve the problem is to discover some means by which the negative ions are separated from their positive fellows and conveyed to the surface of the earth. At present only one theory can be said to be worthy of serious consideration. This is the theory first put forward by C. T. R. Wilson and lately revived and strongly advocated by Gerdien. According to this theory under certain conditions of supersaturation the water vapor of the atmosphere is deposited on the negative ions, these then become the nuclei of raindrops and are ultimately carried to the earth. This theory has a great deal to commend it, but it does not explain all the facts, and is not as yet very generally accepted.

When it was once realized what an important bearing the amount of ionization of the air has on the electrical state of the atmosphere many physicists in Germany undertook long investigations into the variations of the number of ions present in the atmosphere, and endeavored to find how the number varied with different meteorological conditions. The result of this work has given very definite knowledge on these points.

In the first place it has been found that the number of ions present and the freedom with which they move through the air vary greatly from season to season. The summer is accompanied by the greatest conductivity of the atmosphere, while the lowest occurs in midwinter. As the rate at which the electricity is dissipated from the surface depends on the conductivity of the air—i. e., on the number of ions present and their mobility—one would expect greater dissipation in the summer than in the winter; and this is shown to be true by measurements of the electrical field just above the surface, which indicate much greater surface charges during the winter than during the summer. Cold, hazy, foggy, and damp weather are all accompanied by low ionization, while the reverse is the case with warm, bright, and clear weather.

It has long been known that the aurora is an electrical phenomenon of the upper atmosphere, and it was thought very probable that it would influence the electrical conditions of the lower atmosphere; but during a year spent in the region in which auroras are most frequent the present writer has been quite unable to detect any such influence, even though provided with the best and latest instruments.

A great deal of experimental work has been directed toward finding out the condition under which air and other gases can be ionized, and the conclusion reached is that no gas will spontaneously ionize, but that some active agent is necessary. The two best known agents by which gases can be ionized are the X rays and the rays given off from radio-active matter. The question naturally arises as to the agent at work in the atmosphere causing the ionization which we know is always taking place. Ingenious experiments have shown that the air always contains a varying amount of radio-active matter, and is penetrated by a strong X-ray-like radiation, the origin of which has not yet been determined.

The radio-active matter of the atmosphere has an interesting source, and its life history has been clearly indicated by Elster and Geitel.

Among the materials of which the crust of the earth is composed are greater or less amounts of the primary radio-active bodies—radium, thorium, etc. These bodies constantly give off a vapor-like emanation, which for a comparatively short time exists as a radio-active gas and then disappears, at least as far as we are concerned. This emanation collects in the interstices of the soil and in all underground holes, from which it very slowly diffuses into the atmosphere above. When the barometric pressure falls there is naturally a flow of air, heavily charged with emanation, from the ground, so that the amount of emanation in the atmosphere is appreciably greater with a falling than with a rising barometer. The emanation which finds it way into the atmosphere undergoes changes during which it emits Becquerel rays which ionize the air. The study of the varying amounts of emanation in the atmosphere has been already carried very far, and the relation between the amount of emanation and the different meteorological factors is fairly well known. Several eminent physicists have suggested some relation between the amount of radio-active emanation in the atmosphere at any place and the climate there; they explain the "bracing" or "relaxing" condition at two places geographically similar by the differences in the amount of emanation to be found there. These ideas have as yet received no experimental support, still this is an interesting region for speculation.

There is still an immense number of problems to be solved in relation to atmospheric electricity; in fact very few of the problems have received satisfactory answers. The explanation of the aurora is still unknown, nor is there any agreement even as to whether its origin is terrestrial or cosmical. Whether the negative variations which have been so closely studied are connected in any way with atmospheric electricity is still quite unknown, and one can not see much hope for an early solution of the problem.

Even after a century of investigation, the ordinary thunderstorm is still as great a riddle to the modern physicist as it was to Franklin; we do not know how the electrical forces are brought into play, we can not even describe clearly what happens when a discharge takes place, so it is not surprising that we have absolutely no idea why a thunderstorm gives some people headaches and turns milk sour; we do not even know if these things are real or not. As to what globe lightning is we have not yet begun to make intelligent guesses. Nevertheless advances in the unknown regions are being made, and, if the progress of the last ten years continues, more than one of these difficulties will shortly be removed and our knowledge of atmospheric electricity rapidly increased.